NASA/CR—2004-213053

# The Case for Deep Space Telecommunications Relay Stations

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# The Case for Deep Space Telecommunications Relay Stations

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## Abstract

Currently, each future mission to Jupiter and beyond must carry the traditional suite of telecommunications systems for command and control and for mission data transmission to earth. The telecommunications hardware includes the large antenna and the high-power transmitters that enable the communications link. Yet, future spacecraft will be scaled down from the hallmark missions of Galileo and Cassini to Jupiter and Saturn respectively. This dictates that a higher percentage of the spacecraft weight and power must be dedicated to telecommunications system. The following analysis quantifies this impact to future missions and then explores the merits of an alternative approach using deep space relay stations for the link back to earth. It will be demonstrated that a telecommunications relay satellite would reduce telecommunications weight and power sufficiently to add several more instruments. Additionally, alternative system architectures are explored and trade-off presented to arrive at a preliminary system concept for this mission.

## Introduction:

Galileo and Cassini are the hallmark mission spacecraft (S/C) exploring the outer planets. Each contains a myriad of probes, instruments, experiments and the necessary telecommunications systems. In fact, both S/C carry large antennas and the accompanying high power transmitters in order to provide high data-rate communications. Future missions are expected to be significantly scaled down in physical size but to increase in the number of spacecraft missions. This approach mitigates any single S/C catastrophic event. However, currently each mission must carry the same large high gain antennas and high power transmitters of those earlier hallmark missions. As a result, S/C will have a much higher percentage of their weight and power devoted to the telecommunication system hardware. Hence, this study addresses the possibility of placing a telecommunications relay station initially at Jupiter (and later Saturn and beyond). The relay station supports multiple simultaneous smaller missions at Jupiter and to its moons without dedicating significant percentages of future S/C weight and power for their telecommunication systems. For this study, a mission launch date of 2012 is assumed.

## Mission Analysis

The first quantification of weight and power will show the significance of these parameters to future missions. The Galileo mission to Jupiter had a deployable mesh reflector and 100W X-band transmit power. Cassini has a 4.0m graphite epoxy reflector (with multiple feeds for radar mapping) and 120W X-band transmit power. In order to derive weight and power percentages for these missions, assume the transmitter has a 50% efficiency and include the power of the transponder. One can then derive a rough estimate of the weight and power percentage of these previous mission S/C. Now the expected percentages for future missions can be calculated assuming the future mission S/C are in the 800 kg class and the same required weight and power.

Alternatively, if one considers that future mission S/C only require direct communication with the proposed relay station, then these percentages drop significantly. Figures 1 and 2 show the impacts to mass and power for future missions using the telecommunications relay station.

| **Weight (kg)** | **Galileo** | **Cassini** | **Future Smaller Missions** | **Future Mission with JTRS** |
|---|---|---|---|---|
| S/C Weight | 2100 | 2175 | 800 | 800 |
| Antenna and Comm Sys Weight | 126 | 185 | 150 | 50 |
| Percentage Weight | 6.0% | 8.5% | 18.8% | 6.3% |
| **Number of Instruments** | **10** | **12** | **4** * | **5** * |

* potential maximum number

**Table 1. Comparison of Mission Weight**

| **Power(W)** | **Galileo** | **Cassini** | **Future Smaller Missions** | **Future Mission with JTRS** |
|---|---|---|---|---|
| S/C power | 682 | 630 | 460 | 460 |
| Comm Sys Power | 250 | 285 | 280 | 23.6 |
| Percentage Power | 36.7% | 45.2% | 60.9% | 5.1% |
| **Number of Instruments** | **10** | **12** | **3-4** * | **5-6** * |

**Table 2: Comparison of Mission Power**

These future missions can benefit from lower communication system weight and power by either increasing the number or increasing the complexity of each mission's instrument suite. By carrying only a local telecommunication system rather than the complete earth-link system on each mission, sufficient mass and power are available for one to two additional instruments, probes, or experiments as shown in Tables 1 and 2.

This study will focus on the nearest of the outer planets, Jupiter. The proposed telecommunications relay station S/C does not orbit Jupiter but instead, would be positioned at the innermost of Jupiter's five libration points, designated L1 in Figure 1 [1]. These libration points are locations where the Sun-Jupiter gravitational potentials are zero. L1 has the advantage of being a lesser distance from both the host planet and from earth than the others. In fact, a key reason for this location is the void of meteorites due to the gradient of the gravitational potential. That is to say, any moving object would not stop to this location, but a S/C could be placed and maintained there.

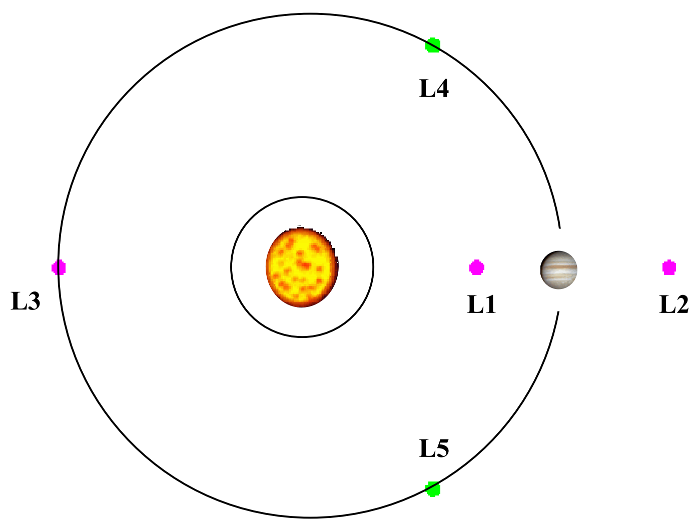


**Figure 1: Jupiter's Libration Points**

## The Link Analysis:

Previous mission analyses have concluded that the downlink is the driving performance specification for deep space communications [2]. Hence, this study will only address the S/C-to-earth link. The Deep Space Network (DSN) is an international network of large steerable reflector antennas supporting most interplanetary spacecraft missions. In addition to communications, the DSN uses these antennas for radio and radar astronomy observations to explore the planets, the galaxy and the universe. The DSN consists of three communications facilities placed approximately 120 degrees apart around the world: in California's Mojave Desert at Goldstone; near Madrid, Spain; and near Canberra, Australia. Each facility has several antennas ranging from 15m to 70m in diameter. The strategic placement permits constant observation of spacecraft as the Earth rotates.

The DSN has been transitioning its primary deep space communications from X-band to Ka-band frequencies, 31.8-32.3 GHz for downlink and 34.2-34.7 GHz for uplink [3]. This permits usage of significantly higher bandwidths at Ka-band, 500 MHz, versus 45MHz at X-band. Hence, Ka-band is assumed to be primary for the relay satellite communications with X-band as a secondary back-up.

Ground rules [4] for this link analysis include using the DSN 34m with a G/T=61dB/K [3] and a minimum data rate of 1 Mb/s with current coding techniques [5].
The Small Deep Space Transponder (SDST) is also assumed for the S/C. The Bit Error Rate (BER) of 10-7 at 0.65dB S/N used is consistent with today's technology assessment [5].

Table 3 shows a preliminary link budget including the key parameters of the analysis. The selection of parameter values reflects mostly maximum conditions to meet the minimum data rate. The earth-to-relay station distance could be as large as Jupiter plus Earth's orbit radius. Nominal values for losses are included for polarization, atmospheric effects, and pointing error. The Effective Isotropic Radiated Power (EIRP) was adjusted until a positive 3dB margin was achieved.

Propagation effects were evaluated based on the favorable locations of the three sites of the DSN ground stations [6], their weather profile, and assuming that if one site had significant rain, that another site is visible and has improved operating conditions. Calculations use the direct sum rather than an RSS since this analysis assumes the quasi-worse case conditions. Table 4 shows the propagation parameters used in the analysis and their corresponding values.

Table 3: Jupiter-to-Earth Link Budget

| Link Budget<br>Communications System Parameters | | Value | Units |
|---|---|---|---|
| Tx | Transmitter Output Power | 25.0 | W |
| | Transmitter Output Power | 14.0 | dBW |
| | Feed Losses | -1.0 | dB |
| | Transmit Antenna Gain | 71.0 | dBiC |
| | Effective Iso Radiated Power | 84.0 | dBW |
| | | | |
| Rx | Signal Frequency | 32.00 | GHz |
| | Path Length | 9.28E+08 | km |
| | Path Loss | -301.9 | dB |
| | TOTAL Atmospheric Losses | -4.5 | dB |
| | Polarization Loss | -0.3 | dB |
| | Pointing Loss | -3.0 | dB |
| | Received Power | -225.67 | dB |
| | | | |
| | Receive System G/T | 61.00 | dB/K |
| | Boltzmann's Constant | -228.6 | dBW/Hz-K |
| | Received C/No | 63.93 | dB/Hz |
| | | | |
| Channel | Channel Bandwidth | 500.00 | MHz |
| | Channel Bandwidth | 87.0 | dB-Hz |
| | Received C/N | -23.1 | dB |
| | | | |
| Data Rate | Bit Rate | 1.00 | Mb/s |
| | Bit Rate | 60.00 | dB-Hz |
| | Received Eb/No | 3.93 | dB |

| | | |
|---|---|---|
| Required Eb/No = | 0.65 | dB |
| Link Margin = | 3.28 | dB |

Table 4: Atmospheric Losses

| Ka-Band Propagation Effect | Losses | |
|---|---|---|
| Rain Attenuation | 0 | dB |
| Atmospheric Gaseous Absorption | 1.2 | dB |
| Cloud Attenuation | 1 | dB |
| Scintillation | 0.8 | dB |
| Atmospheric Noise | 1.5 | dB |
| Multipath | 0 | dB |
| Ground Antenna Moisture | 0 | dB |

| | | |
|---|---|---|
| TOTAL Atmospheric Equivalent Loss = | 4.5 | dB |

The major parameter resulting from this study is the EIRP at a value of 84 dBW. Hence, the first trade involving EIRP, relates the Ka-band transmit power to gain or aperture size. Assuming 70% aperture efficiency, the EIRP dependence on antenna gain and aperture size is related to transmit power as shown in Figures 2 and 3. One can determine from Figure 3, that transmit power less than 10W pushes the antenna towards very large diameters.

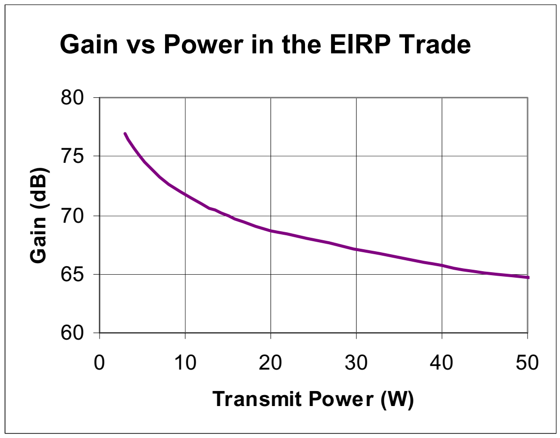


**Figure 2: EIRP Trade for Transmit Power vs Gain**

Yet, these results show the critical range of parameters includes both low transmit power coupled with large diameter apertures. For the remainder of this study, a 13.3m diameter aperture with 15W transmit power is assumed to be near optimum although 11.5m and 20W is equally valid for Jupiter. With a relay station envisioned for Saturn as well at nearly twice the Jupiter link distance, the same antenna can be utilized by increasing the transmit power by a factor of four while still retaining equivalent performance. Hence, 13.3m and 15W are the logical choices for the telecommunications system baseline.

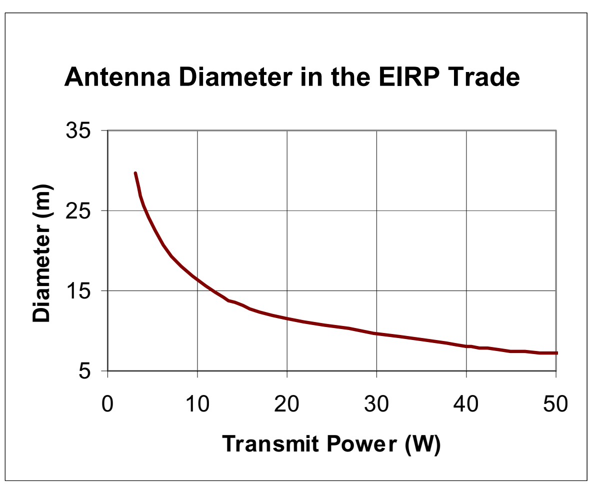


**Figure 3: EIRP Trade for Transmit Power Aperture Size**

## Antenna Survey and Trades

A quick survey of current missions shows that no antenna technology is readily available for this 15m class Ka-band antenna system. Hence a more detailed survey of those emerging technologies for such an aperture will be addressed. Any architecture must be deployable from the launch stowed configuration within the S/C fairing. Typical fairing diameters range between 2 and 4.5m. Three candidate technology approaches are available: (1) Phased Array, (2) Reflectors and (3) Lenses.

To review the state-of-the-art in phased array technology, we take a look at the goals reported for large arrays. These projects have addressed apertures of similar size, but at frequencies much lower. When the aperture parameters are scaled to Ka-band the resulting metrics are expected to be in the range of 3 kg/$m^2$ , 0.35 W/$m^2$, and 100'sK$/$m^2$. Even for a thinned array, the number and density of elements are high and the interconnections are a huge complexity issue. In addition it should be mentioned that significant DC power is required just to maintain the electronics at a high-reliability operating temperature range. But the real issue that currently excludes phased arrays from being a viable technology in this application is the cost. Reported cost Figures far exceed all alternative options. Hence, phased arrays are excluded from further consideration in this application.

Reflectors and Lenses have many more similarities than at first glance. Both require deployment of shaped surfaces, both use external feeds to illuminate their aperture areas, and both require low-loss materials (either reflection or transmission). In addition, their required surface accuracies are within a factor of 2. The obvious significant difference is that one is reflective while the other is transmissive. While many alternate schemes for deployable reflectors have been proposed, lenses have not been as vigorously pursued. Even with this lag, their similarity goes even further. Recently, the same supporting structure used in mesh reflector systems produced for MBSAT and Thuraya [7] has been proposed for waveguide lenses [8,9]. The potential for development of a large deployable lens is not near term for this application. Therefore, only reflectors will be pursued for this study.

Clearly, the leading technology for L-band and lower frequencies for large light-weight deployable reflectors is the Astromesh™ shown in Figure 4. With a stow diameter less than onetenth the deployed diameter, it easily meets the critical stowed-volume packaging constraints. However to date, the surface and surface accuracies suitable for Ka-band operation have yet to be demonstrated in light-weight space-flight systems [10]. This is an area requiring a closer look in this study.

Among the various alternate technologies for reflector surfaces, one of the more interesting approaches is the inflatable surface. Inflatables have been the subject of study for several years. In fact, an initial flight test was performed which was successfully deployed in space [11,12] and shown in orbit in Figure 5. Since that time, continued advancements have taken place. Recently, key developments in materials has enabled this study to take another look at this conceptually promising technology.

**Figure 4: Astromesh™ Reflector (Astro Aerospace web page http://www.astro-aerospace.com)**

**Figure 5: Initial Inflatable Flight Experiment (L'Garde [11] )**

A quick comparison of the properties of the Astromesh™ and inflatables reveals several key distinguishing properties. First is the obvious yet not so apparent observation that the mesh reflector mass increases dramatically with increasing frequency. This is due to two factors. First, the mesh size must decrease with increasing frequency in order to maintain a high reflectivity, hence an increasing mass density. Second, the facet size decreases as a function of frequency, also requires an increasing mass density. The facet size is the smallest increment of surface area created from the multitude of support points. This leads also to an increasing mass density with frequency since more tie points are required the keep the peak surface error a small fraction of a wavelength.

Figure 6 shows the mass reported for mesh and inflatable reflectors based on either direct measurements reported or extrapolation of planned mission mass density for those available in the literature [13,14,15,16,17,18,19,20]. Note that there is little to distinguish the two technologies.

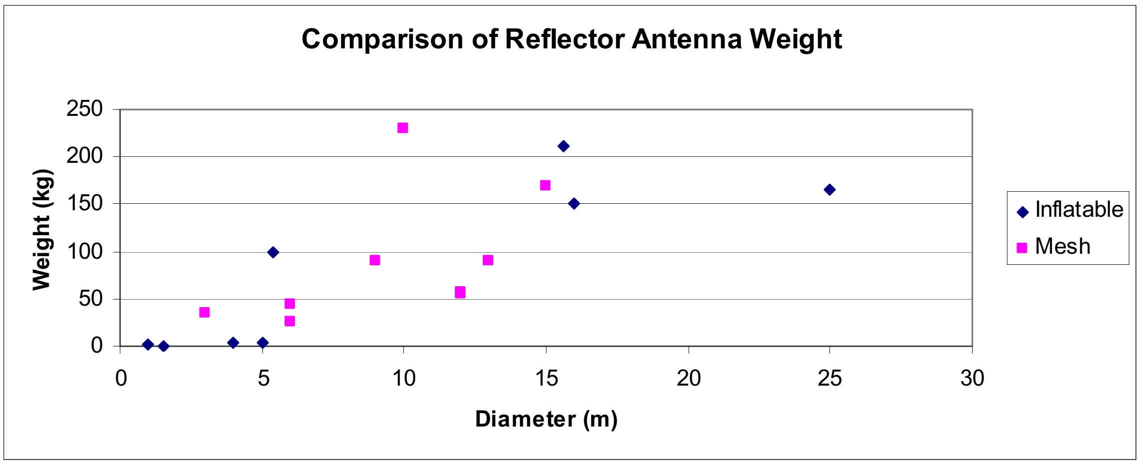


**Figure 6: Estimates of Reflector Mass for Mesh and Inflatables**

Since most of the reported weights for mesh reflectors were at lower frequencies, their weight was scaled to the Ka-band frequency. Both a smaller mesh size and a smaller facet size are required. A smaller mesh size maintains the high reflectivity surface property as a function of the shorter wavelengths. Second, weight must be scaled for the decreasing size of the facet, the smallest incremental surface area. A smaller facet requires an increasing number of tie-points that is increasing in proportion to frequency. These two contributions increase total mesh reflector weight. In this respect, the inflatables have the high-frequency advantage of their performance actually being independent of frequency.

Reflector mass estimates of Astromesh™ have previously used 20% of their weight for the mesh and web structure [10]. In addition, to reconcile all the variations in what constitutes the reflector weight according to those reported in the literature, a system weight was baselined as the key parameter. Deployable support booms were added to the mesh reflector weight and an inflation system added to the inflatable weight. Other adjustments include the feed in baselining system weight. Figure 7 shows that when the mesh reflector weight is adjusted to account for Ka-band operation and to include these other adjustments as described above, inflatables show a clear weight advantage at Ka-band.

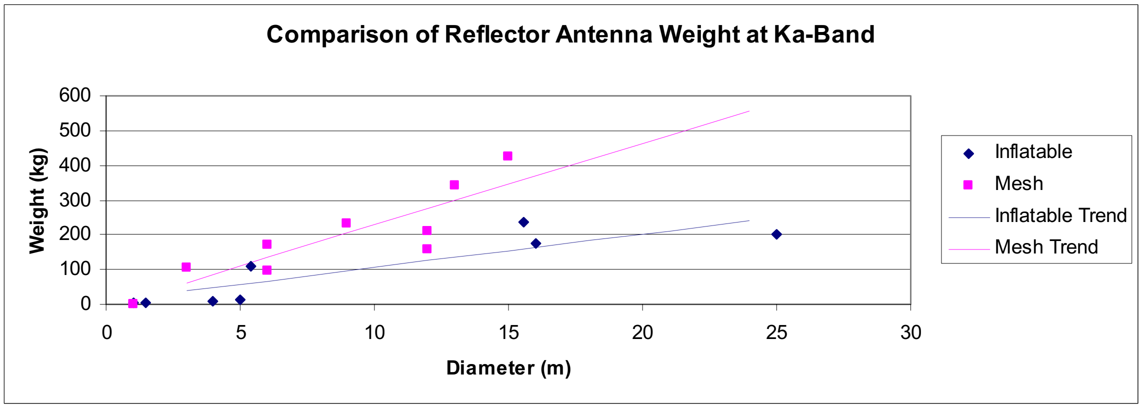


**Figure 7: Comparison of Technologies by Adjusting the Mesh Weight to Ka-Band**

The mesh reflector weight estimate for 13.3m diameter is near 310 kg while the inflatable weight estimate is 135 kg. From Figure 7 it is clear that the mesh reflector has a disadvantage at the larger diameters when scaled for higher frequencies. In fact, the mesh surface has another disadvantage in having peak sidelobes or "grating" lobes due to the finite facet size [10].

The newest approaches to inflatables uses membrane materials developed by NASA Langley Research Center (LaRC) and licensed to SRS Technologies. LaRC CP1™ and CP2™ Polymer Materials have been formed to the reflector shape, thin-film conductively coated, stabilized and thermally set to produce the surfaces in the form suitable for millimeter-wave reflectors. Figures 8 and 9 show the material supported by inflatable torus and a demonstration of the high quality surfaces that are producible.

**Figure 8: Membrane surface supported By Inflated Torus**

**Figure 9: High Quality surface on Membrane materials**

**(SRS Technologies webpage http://www.stg.srs.com/atd/advpolymers.htm)**

Studies show excellent surface properties and now test articles are under development to determine if these membrane materials meet the surface accuracy and stability needs for such a mission. At this point, inflatables appear to be the most promising antenna technology for large Ka-band reflectors.

## Preliminary Requirements

To summarize the results of this study into a concise and usable form, a set of preliminary system requirements was derived for the proposed telecommunication relay satellite link [21]. Included for completeness is the secondary system requirement for X-Band communications as the emergency backup system. Also shown in Table 5 is the derived requirement for Ka-band gain and transmit power from the EIRP. Low gain antennas are included as part of the communications system and only used in a fail-safe mode. Finally, a preliminary block diagram for this system is shown in Figure 10.

**Table 5: Telecommunications Relay Satellite Preliminary Requirements**

| PARAMETER | REQUIREMENT |
|---|---|
| Frequencies | |
| Ka-Band Primary | 34.2-34.7 GHz UL, 31.8-32.3 GHz DL |
| X-Band Emergency | 7.145-7.190 GHz UL, 8.4-8.45 GHz DL |
| Polarization | RHCP |
| EIRP | |
| Ka-Band Primary | 81.7 dBW |
| Gain | 70 dBiC |
| Transmit Power | 15 W |
| X-Band Emergency | 42 dBW |
| Sidelobes | < 20 dB UL |
| S/C Pointing | +/-150 arcsec |
| Data Rate | |
| Ka-Band Primary | 1 Mb/s (minimum) |
| X-Band Emergency | 1 Kb/s (minimum) |
| Life | 15 years |
| Field of Regard | 18.3° |

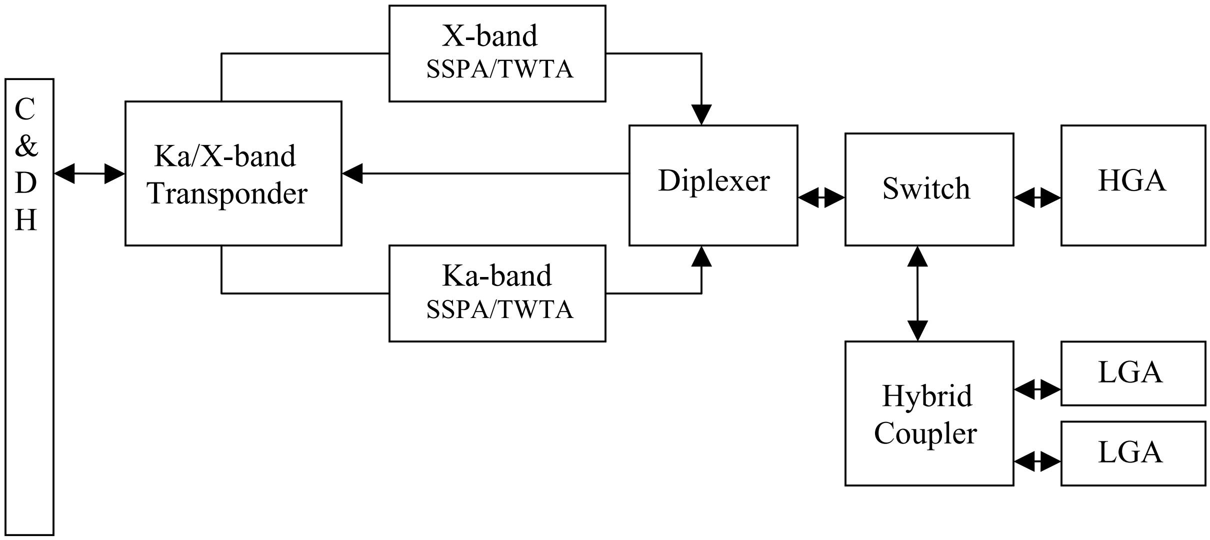


**Figure 10: Telecommunications Relay Station RF Block Diagram**

## Potential Antenna Configurations

Consider the multitude of antenna configurations available for this mission. The most popular choices from previous deep space missions have been either the center-fed full parabolic reflector or the Cassegrain reflector. The center-fed reflector poses difficulty when implemented in large apertures since the transmission lines from the transmitter (on the S/C) to the feed are long (fractions of the reflector diameter). A quick survey of other antenna configurations includes the offset, offset Cassegrain, Gregorian and various dual reflector arrangements. These all have critical alignment issues when either the feed or the reflector is remote from the S/C. The earlier discussion on long transmission line lengths concludes that the reflector must be the one remote. This directly implies two likely operational constraints. 1) The reflector main surface must be deployed (likely from a boom) then opened. 2) A high degree of alignment and stability must be maintained between the reflector surface(s) and the feed. For the Cassegrain, the main reflector is not required to be a continuous conductive surface through the central blockage area. A full paraboloid could be deployed and referenced from the S/C. Hence, the Cassegrain mitigates the previously discussed limitations and constraints of other configurations. This mission's preliminary choice of antenna is the Cassegrain reflector with the feed, subreflector and main reflector mounted "on" the S/C and is beginning point for continuing antenna configuration studies.

## Conclusion

This study has demonstrated that for the smaller satellites envisioned for our future deep space missions, the telecommunications system weight and power will consume significantly larger percentages of the S/C resources than previous missions. As a direct result of each mission carrying the full suite of communications hardware, these smaller-mission S/C will carry several less instruments than a S/C linked through the relay station satellite. Hence, over the many S/C expected to explore these planets and particularly their moons, many additional instruments could be added. With those additional instruments, the data gathering expands to several additional missions worth of data. This approach appears to be the most promising alternative to a direct-to-earth link on each S/C consuming a greater percentage of weight and power. The study further concludes that such a relay station is highly feasible and that a telecommunications relay station at Jupiter and Saturn would support the high data rates required for several simultaneous missions to those planets. Finally, the technology of choice points to the inflatables as to the best technology match for the relay station antenna.

## References

[1] G. Gomez, M.W. Lo and J.J. Masdemont, *Proceedings of Libration Point Orbits and Applications*, Aiguablava, Spain, June 2002.

[2] Kuiper, T.B.H and Resch, G.M., Deep Space Telecommunications, JPL Tech Memo, DEEP SPACE TELECOMMUNICATIONS, Jet Propulsion Laboratory 169-506 California Institute of Technology Pasadena, CA.
www.astron.nl/documents/conf/technology/tech08w.pdf

[3] Ludwick, B., Prongay, R., Shieh, T. and Walter, R., "Downlink Frequency Usage for Deep Space Missions, JPL Tech Memo.
www.198.11.21.25/capstoneTest/Students/Papers/docs/DownlinkFreqDeepSpace310222.pdf

[4] Maral G and Bousquet M, eds., *Satellite Communications Systems*, John Wiley (1993).

[5] Noreen, G.K., “Deep Space Network Support for Small Missions”, JPL Tech Memo. www.upv.es/satelite/trabajos/pracGrupo15/ Marte/DSN/PDF/Dsns.pdf

[6] Acosta, R., et al., NASA’s New Radio Wave Propagation Experiment, 8th Ka-Band Utilization Conference, Baveno/Stresa, Italy, September 26, 2002.

[7] Thomson, M.W., The Astromesh Deployable Reflector, Proc. 5th International Mobile Satellite Conference (IMSC’97), June 1997, Pasadena CA, JPL Publication 97-11.

[8] M. Hamidi, J. Withington, E. Wiswell, “Deployable RF Lens Antenna” AIAA 20th Conference on Satellite Systems, Montreal, Canada, May 12 – 15, 2002.

[9] Wolcott; James L; Bartholomew, III; John R.; Chandler; Charles W., Ultralight collapsible and deployable waveguide lens antenna system, United States Patent 5,818,395, October 6, 1998.

[10] Thomson, M.W., Astromesh™ Deployable Reflectors for Ku and Ka-Band Commercial Satellites, Proc. 20th AIAA International Communications Satellite Systems Conference, Montreal, Canada, May 2002.

[11] “Preliminary Mission Report: Spartan 207/Inflatable Antenna Experiment Flown on STS-77”, Spartan Project, NASA-GSFC, Feb. 14, 1997.

[12] Freeland, R. E., Large Inflatable Deployable Antenna Flight Experiment Results, Proc. IAF, IAF-97-1.3.01, 1997.

[13] Schaubert, D. et al., Large, Lightweight Deployable Antennas, Earth Science Enterprise Technology Planning Workshop, January 2001.

[14] “Innovative Space-based Radar Antenna Technology (ISAT)”, DARPA PRDA-01013-IFKPA, August 2001.

[15] Dornheim, M.A., Inflatables Taking to Flight, Aviation Week & Space Technology, www.lgarde.com/programs/iaearticle/awarticle.html.

[16] "TRW Completes CDR for Inmarsat 4 Mesh Reflectors", Space Newsfeed, 8 July 2001, www.spaceneswfeed.co.uk.

[17] Willey, C.E et al., A Hybrid Inflatable Dish Antenna System for Spacecraft, AIAA 2001-1258, AIAA Gossamer Spacecraft Forum, Seattle, WA, April 16-19, 2001.

[18] Whittinghill, C. M., A Study of the Feasibility and Applicability of Shape Controlled Space Based Inflatable Membrane Structures, Naval Postgraduate School, Monterey CA, Sept. 2000.

[19] Yamazoe, Y. et al., Proposal of the satellite mission: Inflatable technology Demonstration Satellite "ASAGAO", Nakamura Laboratory, Nihon University, 1999.

[20] Thomas, M. and G. J. Friese, Pressurized Antennas for Space Radars, AIAA, 1980, www.lgarde.com/people/papers/radar.html.

[21] Larson W and Wertz J, eds., *Space Mission Analysis and Design*, 2nd Ed, Kluwer Academic Publishers (1992).

## Bibliography

*DSMS Telecommunications Link Design Handbook*, 810-005, Rev E, Jet Propulsion Laboratory, Pasadena, CA, Nov. 30, 2000.

Ippolito, L. J., *Propagation Effects Handbook for Satellite Systems Design*, 5th Edition, ITT Industries, September 2000.

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**13. ABSTRACT *(Maximum 200 words)***

Each future mission to Jupiter and beyond must carry the traditional suite of telecommunications systems for command and control and for mission data transmission to earth. The telecommunications hardware includes the large antenna and the high-power transmitters that enable the communications link. Yet future spacecraft will be scaled down from the hallmark missions of Galileo and Cassini to Jupiter and Saturn, respectively. This implies that a higher percentage of the spacecraft weight and power must be dedicated to telecommunications system. The following analysis quantifies this impact to future missions and then explores the merits of an alternative approach using deep space relay stations for the link back to earth. It will be demonstrated that a telecommunications relay satellite would reduce S/C telecommunications weight and power sufficiently to add one to two more instruments.

**14. SUBJECT TERMS**

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